Interactions Among Western Corn Rootworm (Coleoptera: Chrysomelidae), Yellow Foxtail, and Corn

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ABSTRACT Field studies at sites with two contrasting soil types investigated effects from the presence of yellow foxtail [*Setaria pumila* (Poir.) Roem. and Schult.], established in bands parallel to corn rows, on western corn rootworm (*Diabrotica virgifera virgifera* LeConte) survival, corn root injury, lodging, biomass production, and yield. Results suggested that the presence of foxtail as an alternate host influenced the degree and progression of corn rootworm damage and adult emergence in a given locality. Rootworm adults emerged later from foxtail band areas and had smaller head capsule size than did individuals from areas without foxtail, consistent with earlier findings that foxtail in the diet of western corn rootworm was a poor nutritional substitute for corn. Lodging was reduced in the presence of yellow foxtail in some cases, but corn stover biomass and yield also were lower. Influences, if any, of soil type on rootworm survival were unclear because of differences in planting date between the two sites. Foxtail may function as a buffer to reduce rootworm damage to corn and serves as an alternate host that should be considered in the development of resistance management strategies for transgenic corn modified for rootworm resistance.

KEY WORDS insect-plant interactions, alternate hosts, *Diabrotica* spp., larval movement, resistance management

Corn rootworms (*Diabrotica* spp.) are destructive insect pests in the corn-producing regions of North America (Levine and Oloumi-Sadeghi 1991). In the absence of effective management, larval injury to the corn root system disrupts water relations (Riedell 1990), affects nutrient content (Kahler et al. 1985), and reduces plant stability (Spike and Tollefson 1989). The adult stage feeds on corn pollen, silks, and developing ears (Gray and Tollefson 1988, Spike and Tollefson 1989). Feeding injury often results in secondary effects that include lower yield, plant lodging, and increased disease susceptibility (Chiang 1973).

Although insecticide application and crop rotation persist as primary management tactics for corn rootworms (Foster et al. 1986), the advent of transgenic rootworm-resistant varieties represents a new approach to rootworm management, the full impact of which has yet to be realized. Effectiveness of transgenic corn against rootworms may be influenced by alternate graminaceous hosts on which larvae of western corn rootworms may feed if corn roots are not available (Bergman and Turpin 1984, Strnad et al. 1986). Larval development of western corn rootworm, *Diabrotica virgifera virgifera* LeConte, was supported on 18 of 44 grass species, including wheat, barley, green foxtail, and yellow foxtail, which were tested by Branson and Ortman (1967, 1970). Foxtails, *Setaria* spp., share similar root structure, density, and chemical metabolites, and are a commonly found weed complex in Midwestern corn fields (Branson and Ortman 1970, Johnson et al. 1984).

Alternate hosts often are a poor substitute for corn roots in the diet of corn rootworm larvae. The total number of emerged adult western corn rootworm beetles and individual beetle weight were reduced when larvae fed on roots other than corn (Branson and Ortman 1967, 1970; Johnson et al. 1984). Developmental abnormalities, such as reduced head capsule width or wing deformity, were observed by Branson and Ortman (1967, 1970) among rootworm adults reared on alternative hosts.

Unlike roots of the grass species, broadleaf weed (12 species) and crop (15 species) roots did not sustain growth of western corn rootworm larvae (Branson and Ortman 1970). Rotation to a nonhost broadleaf crop, such as soybean, has been considered good management practice for corn rootworms (Turpin et al. 1972, Foster et al. 1986). However, some populations of corn rootworms survive in soybean fields through extended egg diapause, oviposition in the soil of soy-

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bean fields, and fortuitous development as larvae on volunteer corn. Neonate corn rootworm larvae must locate roots of a suitable host plant within 24 h of hatch or the likelihood of survival is greatly reduced (Branson 1989). Western corn rootworm larvae are affected by physical properties of soil (Turpin and Peters 1971). Favorable conditions (i.e., loam or clay type soils, moist soil, minimal compaction, abundant pore space) increase survival, whereas unfavorable conditions (i.e., sandy soil types, dry or saturated soils, compacted soils, restricted pore space) increase mortality (Lummus et al. 1983, MacDonald and Ellis 1990). Clearly, many environmental, host plant, and soil factors interact to influence the survival of western corn rootworm larvae. The objectives of these field studies were to determine the influence of yellow foxtail on corn-rootworm survival and injury to corn, to determine how increasing distance of egg placement from the corn row influences rootworm survival in the presence and absence of yellow foxtail, and to compare the above interactions in contrasting soil types.

Materials and Methods

Site Description. These studies were conducted in 1995 and 1996 at two field locations near Brookings, SD (44°19′ N, 96°46′ W, ≈500 m altitude). One location was 2.3 km north of Brookings at the Eastern South Dakota Soil and Water Conservation Research Farm (Brookings site) on a light-colored Vienna loam (fine-loamy, mixed Udic Haploboroll; 45% sand, 34% silt, and 22% clay). The second location was 6.7 km east of Brookings near the Aurora Research Farm (Aurora site) of South Dakota State University (SDSU) on a dark-colored Brandt silty clay loam (fine-silty, mixed Udic Haploboroll; 17% sand, 56% silt, and 27% clay). Fields at both locations sloped slightly (0–2%) from north to south at the Brookings site and from south to north at the Aurora site. Because of the higher proportion of sand in the Vienna soil series, the Brookings site was the better drained of the two. The Aurora site retained soil moisture also because of higher organic matter content and the north-facing aspect of the plot area. Both sites had management history as a corn/soybean rotation under conventional tillage, with rows running east to west at the Brookings site and north to south at the Aurora site. Corn (Pioneer 3769) was planted in single rows on 1.5-m centers to provide sufficient isolation between treatments for precluding the movement of corn rootworm larvae between plots. Soil temperatures were monitored at 10 cm depth under turf (Brandt soil series) at a weather station located on the SDSU Agronomy Farm, about midway between the two experimental sites. These temperature data were used to calculate soil growing degree-days (GDD) above a base of 10°C and below an upper limit of 30°C. Precipitation data were obtained from records kept at the SDSU Aurora Research Farm ≈1.7 km west of the Aurora site and at the Eastern South Dakota Soil and Water Conservation Research Farm for the Brookings site. Data for 30-yr precipitation averages were obtained from historical records of the weather station on the SDSU Agronomy Farm.

Experimental Treatments and Design. Treatments present in both years of the study consisted of single corn rows subjected to combinations of yellow foxtail, *Setaria pumila* (Poir.) Roem. and Schult., and western corn rootworm egg infestations applied at various distances on one side and parallel to the corn row. Nine treatments present in both years were (1) corn with no yellow foxtail and no rootworm eggs; (2, 3, and 4) corn with a zone of rootworm eggs infested parallel to and 10, 20, or 30 cm, respectively, from the row; (5, 6, and 7) corn with a zone of rootworm eggs infested parallel to and 10, 20, or 30 cm, respectively, from the row with a 10-cm-wide strip of yellow foxtail also established parallel to and between the corn row and egg zone; and (8 and 9) corn with a zone of rootworm eggs placed 20 or 30 cm, respectively, from and parallel to the corn row with a 10-cm-wide band of yellow foxtail adjacent to and between the egg zone and corn row. In 1996, a 10th treatment was included as a zone of western corn rootworm eggs infested directly into the corn row without presence of yellow foxtail. Treatments were arranged in a randomized complete block design with four replications. Plots at both locations extended 0.5 m to either side of the corn row (1 m wide) by 10 m long in 1995, and 1 m wide by 15 m long in 1996. Spacing between plots was 0.5 m to isolate treatments.

Corn and Foxtail Cultural Practices. Seedbed preparation consisted of one pass with a field cultivator in the spring. 'Pioneer 3769' (97-d maturity) corn was planted in 1995 to a density of ≈69,000 plants/ha using a single-row push-type seeder on 19 May at the Brookings site and 26 May at the Aurora site. In 1996, corn was planted on 16 May at the Brookings site and 24 May at the Aurora site using a 6-row corn planter, with every other bin plugged to achieve the desired row spacing for isolation. Immediately after corn planting, yellow foxtail seed was distributed in a 10-cm band using a modified fertilizer drop-spreader at the proper placement relative to the corn and rootworm egg bands. Foxtail seed was lightly raked into the soil and thinned after emergence to a density of ≈550 plants/m^2.

Weeds other than foxtail were controlled each year by chemical treatments applied in early June after the plots were established. A broadcast application of dicamba herbicide (diglycolamine salt of 3,6-dichloro-*o*-anisic acid) was done over the entire site at a rate of 474 g AI/ha to control broadleaf weeds. Alleys, borders, and plots without foxtail received nicosulfuron (2-((4,6-dimethoxypyrimidin-2-yl)aminocarbonyl))-(2-(((((4,6-dimethoxypyrimidin-2-yl)aminocarbon yl))aminosulfonyl))-*N,N*-dimethyl-3-pyridinecarboxamide) at a rate of 35 g AI/ha to control grasses. Late-emerging weeds were removed by hand cultivation as necessary throughout the remaining season. In mid-June, 5-m sections of row near the midpoint of each plot were marked for harvest sampling and yield measurements. During the field season, destructive sam-

Table 1. Monthly precipitation and soil GDD (base 10°C) for 1995 and 1996 at the Aurora and Brookings sites

Month	Precipitation (cm)					Soil GDD		
	30-yr ave	Aurora—Brandt soil		Brookings—Vienna soil				
		1995	1996	1995	1996	30-yr ave	1995	1996
May	7.4	10.9	11.3	11.0	11.0	168	104	137
June	11.0	7.6	7.9	6.7	6.0	266	282	307
July	8.4	19.3	3.2	20.1	1.6	344	334	334
Aug.	7.1	15.6	15.1	12.2	7.1	310	364	365
Sept.	6.7	4.6	6.7	4.5	5.8	187	181	211
Total	40.8	58.0	44.2	54.5	31.5	1275	1265	1354

The 30-yr averages (1964–1994) for precipitation and soil GDD were calculated from South Dakota state climatological records.

pling (i.e., root ratings and emergence cage placement) was done outside the marked areas.

Western Corn Rootworm Infestation. Eggs of western corn rootworm, produced in the rearing facility of the Northern Grain Insects Research Laboratory, USDA, ARS, Brookings, SD, were suspended in a 0.15% agar solution and stored at 10°C until needed in the field. The agar solution kept the rootworm eggs in suspension, enabling accurate and uniform delivery of eggs at a rate of 1,800 viable eggs per row-meter. Appropriate treatment plots were infested on the same day as corn and foxtail were seeded. The egg and agar suspension was applied through a 4-mm (i.d.) tube mounted to the rear edge of a single-shank fertilizer knife, powered by a small horticultural tractor, and set to run 6 cm deep at the desired treatment distance from the corn row.

Emergence cages (100 cm long by 60 cm wide), similar to the design of Siegfried and Mullin (1990), were installed in mid-July to monitor numbers of emerging adult western corn rootworms. Each cage was centered over the corn row, with the long axis parallel to the row, enclosing stubs of five corn plants that were cut just above ground level. The vertical sides of the cages were fabricated from 22-gauge sheet metal, and the top was covered with steel mesh (25 gauge, ≈1-mm openings). The cage sloped upward to one corner so that emerging adults moved to a plastic collection tube containing Vapona killing agent (Loveland Industries, Greeley, CO) and located at the highest corner (Siegfried and Mullin 1990). Each cage was open to the soil surface, and the bottom edges of the side panels were driven ≈5 cm into the soil to prevent beetles from escaping and force them toward the collection tube. Adult western corn rootworm beetles were counted, removed from each cage, and preserved by freezing twice weekly until emergence ended in early September.

In 1996, smaller, additional emergence cages (100 cm long by 30 cm wide) were positioned over corn rows and over yellow foxtail bands to differentiate between rootworm beetles that emerged from corn and yellow foxtail roots. The collection tubes of these cages did not contain a killing agent, thus permitting capture of live western corn rootworm beetles for preservation in 70% ethanol. Two hundred preserved beetles (100 from corn and 100 from yellow foxtail) from each location were randomly selected and head capsule width of each was measured.

Corn Sampling. In mid-July, five corn root systems were dug from each plot. The roots were power-washed to remove loose soil, and were visually rated for rootworm larval injury using the 1–9 scale of Welch (1977). This scale was chosen because prior literature on the soil ecology of rootworms also used the method. A rating of 1 was indicative of no noticeable feeding damage, 4 indicated one to three roots pruned, but less than an entire node with outer roots having moderate feeding damage, 7 was equivalent to one node destroyed, and 9 indicated that three or more full nodes of roots were pruned.

The percentage of lodged corn plants was determined in mid-October, a few days before fall harvest. The total number of corn plants bearing an ear of corn and the number of lodged corn plants were counted in each plot. Corn plants were considered lodged if they were lying on the ground or were severely leaning (at an angle of 60° or more). Corn ears were hand-harvested, dried, weighed, and shelled after black layer formation. Grain yield (corrected to 15.5% moisture) was calculated. All corn plants in the harvest area were clipped at ground level, dried at 60°C to constant weight in a forced-air oven, and weighed to determine stover biomass.

Statistical Analysis. Data were analyzed using SAS software (SAS Institute 1989). Analysis of variance (ANOVA) was used to determine the significance of treatment means. Except where noted, a significance

Table 2. Influence of yellow foxtail on Julian days to 10, 50, and 90% cumulative western corn rootworm adult emergence averaged over egg band infestation distance and soil type in 1995 and 1996

Foxtail treatment	Percent cumulative emergence					
	1995			1996		
	10	50	90	10	50	90
No foxtail (Julian day)	207	218	222	207	213	214
Foxtail present (Julian day)	218	228	231	210	217	219
LSD ($P = 0.05$)	4	4	3	NS	2	3

NS, not significant.

level of 5% was used to determine differences in observations. Orthogonal contrasts were used to compare mean values of corn parameters (yield, plant biomass, percentage of plants lodged, and root damage) by treatment and soil type. Daily emergence data were analyzed as the proportion of the total number of beetles collected per plot per day, transformed to logits by the equation logit $= \ln[x/(1 - x)]$, where x = the proportion of beetles collected. Values equal to 1 were omitted because $\ln(1/0)$ is undefined. A linear relationship over time was approximated by regression analysis (Johnson et al. 1984) to quantify the relationship of beetle emergence (expressed as 10, 50, and 90% cumulative emergence) with cumulative soil GDD from planting date and with distance of rootworm egg infestation sites from the corn row.

Results and Discussion

The 1995 growing season was wet, with ≈40% more precipitation than average, although soil temperature expressed as GDD was near the 30-yr average (Table 1). Precipitation above normal during 1995 occurred in May (54%), July (100%), August (59%), and September (49%), whereas precipitation in June was 37% below normal. The 1996 growing season was warmer and drier. Accumulations of soil GDD (base 10°C) were ≈6% above the 30-yr average (1964–1994) in 1996. Total precipitation in 1996 over the growing season was slightly above normal at the Aurora site and ≈35% below the 30-yr average at the Brookings site. Although rainfall in May 1996 was ≈50% above normal at both sites, deficits of 28–45% and 62–81% in June and July, respectively, resulted in the lower season totals and a relatively dry growing season.

Western Corn Rootworm Beetle Emergence. In 1995, times to 10 and 90% total emergence of western corn rootworm beetles averaged over soil type were 11 and 9 d later, respectively, when yellow foxtail was present (Table 2). In 1996, times to 10% beetle emergence were similar regardless of foxtail treatment. However, time necessary for 90% emergence was 5 d longer when yellow foxtail was present. Recovery of adult western corn rootworm (based on 1,800 viable eggs per row-m) was 7 and 10% in 1995 and 1996, respectively, of total eggs applied. While soil type was not a significant factor in ANOVA analysis (1995, $F = 2.63$ df = 1,3; $P = 0.20$; 1996, $F = 7.33$ df = 1,3; $P = 0.73$), there were more rootworm beetles recovered each year from the Brandt silty clay loam (average 12% survival) than the Vienna loam (average 6% survival).

Time from infestation to 50% emergence of adults was delayed, in both soil types, in the presence of yellow foxtail by 10 and 4 d in 1995 and 1996, respectively (Table 3). The emergence of 10, 50, and 90% of total surviving adult rootworms in 1995 occurred 10–17 d earlier from Vienna loam than from Brandt silty clay loam (Fig. 1; Table 2). In 1996, time to 10% cumulative emergence was 6 d earlier from the Vienna loam, but times to 50 and 90% emergence were similar for both soil types.

Table 3. Influence of soil type on Julian days to 10, 50, and 90% cumulative western corn rootworm adult emergence averaged over egg band infestation distance and foxtail presence or absence in 1995 and 1996

Soil type	Percent cumulative emergence					
	1995			1996		
	10	50	90	10	50	90
Vienna loam (Julian date)	202	215	220	206	214	217
Brandt silty clay loam (Julian date)	219	227	230	212	216	218
LSD ($P = 0.05$)	5	4	4	3	NS	NS

NS, not significant.

Emergence data based on calendar day may be misleading because planting and infestation dates may vary from year to year in a given field. Corn rootworm emergence was interpreted with respect to cumulative soil GDD from time of planting and infestation calculated from records at an SDSU weather station with the caveat that soil GDD were not measured at each site, and thus, emergence was considered in relation to soil GDD from a common reference site. Differences were noted between years and soil types for percentage adult rootworm emergence referenced to soil GDD (Fig. 1). The 10% emergence from the Vienna loam and Brandt silty clay loam occurred at ≈1,000 and 1,300 GDD, respectively, in 1995, a relatively wet year. The 90% emergence level occurred at 1,370 GDD in the Vienna loam and was delayed to ≈1,500 GDD in the Brandt silty clay loam. We surmise that higher moisture content in the Brandt soil, associated with a north-facing aspect and darker color (i.e., higher organic matter content), resulted in slower soil GDD accumulation at that (wetter) site with respect to the site of GDD measurement. The high specific heat of water in the wetter Brandt soil required absorption of solar energy to accumulate the same GDD (Brady 1990), thus delaying emergence of rootworms from the Aurora (Brandt soil) site. In 1996, a drier year, the 10% emergence level occurred at ≈1,125 GDD for each soil, and 90% emergence level occurred at 1,250 GDD for the Brandt silty clay loam and 1,325 GDD for the Vienna loam. These data suggest that western corn rootworm emergence from the lighter-colored and relatively sandy Vienna loam was similar in either a wet or a dry year. In the darker Brandt silty clay loam soil, increased soil moisture in a wet year (1995) may have contributed to slower soil GDD accumulation and thus to a delayed rootworm beetle emergence compared with emergence in a drier year (1996).

Band distance of rootworm eggs from the corn row influenced adult beetle emergence for data pooled across foxtail and no-foxtail treatments significantly in 1996 ($F = 4.61$; df = 4,12; $P < 0.05$), but not in 1995 ($F = 3.46$; df = 3,9; $P = 0.06$). Regression analysis (Fig. 2) combined over soils and years for plots with and

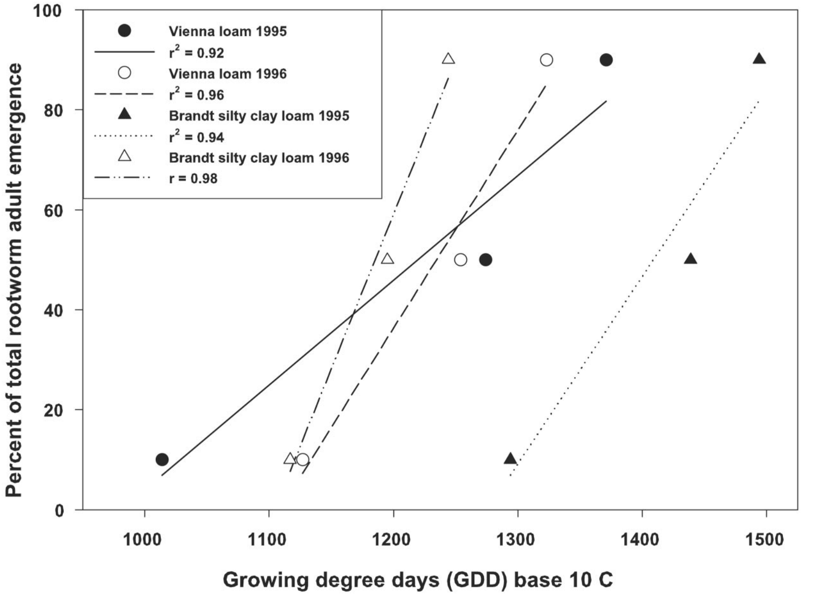

Fig. 1. Cumulative percent of total emergence of surviving adult *D. virgifera* in 1995 and 1996 from Brandt silty clay loam and Vienna loam plotted against soil GDD.

with out foxtail indicated a significant negative correlation between distance to the corn row and adult emergence (1995, $r^2 = 0.98$; 1996, $r^2 = 0.88$; $P = 0.01$ for all values). There were 100% more beetles collected in 1995 from bands within 10 cm of the corn row than from bands placed 30 cm from the corn, suggesting that larvae may have moved through the soil or that infested corn roots may have grown under the area subtended by the emergence enclosure. In 1996, similar numbers of adults emerged from either the band of eggs placed directly over the row or at 10-cm distance. The total number of beetles captured in the presence of yellow foxtail was lower by 50% during 1996 (1995: $F = 0.40$, df = 1,3, $P = 0.57$; 1996: $F = 18.5$; df = 1,3; $P < 0.05$) compared with plots where no yellow foxtail was planted (data not shown). In addition, head capsule widths of adult western corn rootworm beetles collected above the yellow foxtail band

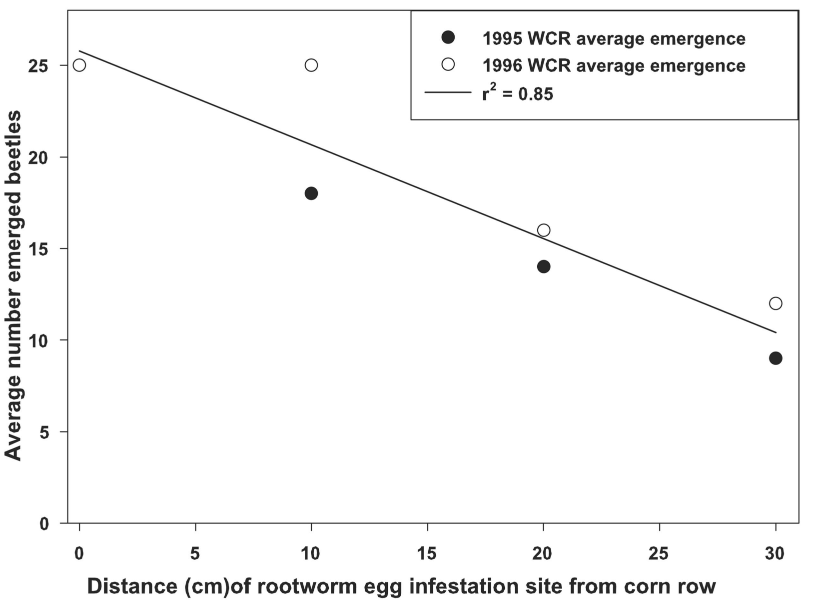

Fig. 2. Regression of surviving adult *D. virgifera* emergence totals against distance of mechanical infestation site from the corn row. Emergence data were combined over years and soil types.

Table 4. Influence of western corn rootworm with and without yellow foxtail infestations on corn root injury, lodging during the growing season, and stover and grain yield at harvest in 1995 and 1996 on a Vienna loam and Brandt silty clay loam soil

Treatment no.	1995						1996			
	Distance from corn row (cm)		Preharvest		Harvest (kg/ha)		Preharvest		Harvest (kg/ha)	
	Rootworm eggs	Yellow foxtail	Root rating[a]	Lodged plants(%)	Stover	Yield	Root rating	Lodged plants (%)	Stover	Yield
					Vienna soil series					
1	Control		1.4	10.5	4,380	5,455	1.2	2.2	11,915	3,430
2	0	—	—	—	—	—	7.3	23.5	11,195	3,363
3	10	—	2.9	26.0	4,320	5,395	6.9	25.0	11,435	3,448
4	20	—	2.6	11.9	4,090	4,575	6.4	12.1	11,855	3,380
5	30	—	2.6	10.2	3,660	4,570	5.2	13.0	12,290	3,383
6	10	0	3.1	21.6	3,915	4,380	5.7	7.8	9,565	3,339
7	20	0	2.7	7.8	4,245	3,985	6.4	8.2	9,015	3,165
8	30	0	2.8	3.7	3,785	3,550	5.1	8.3	10,880	3,159
9	20	20	3.3	10.3	4,370	4,190	5.5	14.3	10,870	3,314
10	30	30	2.4	13.3	3,655	4,505	5.2	8.4	9,195	3,241
					Brandt soil series					
1	Control		1.7	2.7	6,360	4,010	1.3	67.9	14,150	3,428
2	0	—	—	—	—	—	4.4	98.9	13,270	3,211
3	10	—	2.9	11.4	7,760	4,860	5.0	94.4	15,580	3,559
4	20	—	3.0	12.9	6,765	4,690	4.8	95.6	13,080	3,155
5	30	—	2.8	7.4	6,960	5,545	3.6	87.4	12,615	3,270
6	10	0	2.9	22.1	6,080	5,270	5.4	96.3	13,110	3,307
7	20	0	2.9	17.0	6,470	5,585	5.2	97.5	12,220	3,257
8	30	0	2.7	11.7	7,245	4,940	3.6	79.8	10,760	2,979
9	20	20	2.5	20.5	6,495	5,566	3.9	87.3	14,230	3,506
10	30	30	3.0	12.0	6,760	5,270	3.9	77.3	11,625	2,993
					Orthogonal comparisons					
						P value				
Treatment 1 versus 3, 4, and 5			0.0001	—	—	—	0.001	0.001	—	—
Treatment 3 versus 6			—	—	—	0.095[b]	—	—	0.020	—
Treatment 4 versus 7 and 9			—	—	—	—	0.016	—	—	—
Treatment 7 versus 9			—	—	—	—	—	—	—	—
Treatment 5 versus 8 and 10			—	—	—	—	—	0.023	0.038	—
Treatment 8 versus 10			—	—	—	—	—	—	0.023	—

[a] Root injury rating on 1–9 scale (Welch 1977), 1 = no injury and 9 = three nodes destroyed.
[b] Done for Vienna soil series only.

(data collected in 1996 only) were significantly smaller ($F = 18.62$; df = 1,387; $P < 0.001$) than head capsule widths of beetles from corn.

Corn Injury and Yield. Corn roots from treatments with egg infestations had more injury than roots from the egg-free controls (Table 4). In 1995, corn root feeding injury was similar in both soils with slightly more injury in plots with western corn rootworm (average rating of 2.6, indicating many feeding scars) than the control (average rating of 1.5, indicating few feeding scars). In 1996, feeding injury was greater than in 1995. Soil type influenced feeding injury with corn roots from the Vienna having more injury (average rating of 5.5, indicating more than three roots pruned with considerable feeding injury to the outer portion of the root) compared with roots from the Brandt soil (average rating 3.8, indicating two roots pruned and only moderate feeding injury to the outer roots). In 1996, root injury was greater when the yellow foxtail band was positioned beside the corn row (average root rating of 5.7) than when the foxtail band was positioned 10 cm from the corn row between the corn and egg infestation (average root rating of 4.6).

Lodging of corn plants was not influenced by soil type in 1995 ($F = 0.04$; df = 1,3; $P = 0.85$). In 1996, corn plant lodging was ≈90% greater in the Brandt silty clay loam than in the Vienna loam ($F = 361.94$; df = 1,3; $P < 0.05$), a difference that probably resulted from strong winds through the Brandt soil plot area in July and was not due entirely to root feeding injury by *D. virgifera.* The number of lodged corn plants was 65% less ($F = 21.2$; df = 1,3; $P < 0.05$) when yellow foxtail was present than in corn-only plots in 1995.

Corn stover biomass over all treatments (Table 4) was 65 and 20% greater in 1995 and 1996, respectively (1995: $F = 115.7$; 1996: $F = 49.18$; df = 1,3, $P < 0.05$) from the Brandt silty clay loam than the Vienna loam. In 1995, distance to corn rootworm infestation and yellow foxtail treatment did not influence the amount of stover biomass at harvest ($F = 3.21$; df = 2,6; $P =$

0.11). Orthogonal comparisons shown in Table 4 suggest that stover biomass amounts were greatest when yellow foxtail was not present than when yellow foxtail was present in plots with rootworm eggs infested at distances from the corn row of 10 (treatments 3 versus 6, $P = 0.020$) and 30 cm (treatments 5 versus 8, 10, $P = 0.038$). Distance of foxtail from the corn row also influenced stover biomass production (treatments 8 versus 10, $P = 0.023$, Table 4).

Grain yield (Table 4) was ≈13% greater from plants grown in the Brandt silty clay loam compared with yield from plants grown in the Vienna loam in 1995 ($F = 50.134$; df = 1,3; $P < 0.05$), but yields in 1996 were similar between the two soil types ($F = 0.79$; df = 1,3; $P = 0.44$). Yield was reduced for corn from the Vienna loam in 1995 (Table 4) when foxtail was present next to the corn row compared with no foxtail present (treatments 3 versus 6, $P = 0.095$). Other orthogonal treatment comparisons for yield were not significant.

Presence of yellow foxtail between corn rows and the zones of rootworm egg application probably contributed to a reduction of corn rootworm damage and less subsequent lodging of corn. Thus foxtail may provide a buffer to rootworm damage to corn, with the caveat that unlimited foxtail growth will lead to crop yield losses because of foxtail interference (Lindquist et al. 1999). Adults emerged later from foxtail band areas and had smaller head capsule size than did individuals from areas without foxtail. This is consistent with the findings of Branson and Ortman (1967, 1970) that foxtail in the diet of western corn rootworm was a poor nutritional substitute for corn. Even so, the data herein suggest that, whereas the development and fitness of surviving rootworm individuals was affected, foxtail and other graminaceous weeds may serve as hosts for corn rootworms. We surmise that, in plantings of Bt corn with rootworm resistance, weedy grasses may influence the survival and population dynamics of the target pest. Our data support the conclusion of Hibbard et al. (2003), suggesting that alternate hosts may provide a resource from which larger, less susceptible larvae may transfer to transgenic roots, survive, and contribute susceptible individuals to the emerging adult population. Further research is warranted to provide better understanding of potential interactions between corn rootworms and the edaphic environment, transgenic corn, and alternate hosts to make reliable recommendations regarding resistance management in situations where foxtail and other grassy weeds are likely to be factors.

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